THE REMOTE SENSING NEEDS OF ARCTIC GEOPHYSICS

By

William J. Campbell

Introduction

The dynamic world of snow and ice embraces a great part of the earth, and it is one part of the earth's environment that can only be properly studied by remote sensing from aircraft or satellite. At any given time snow covers approximately 13% of the world ocean area. In terms of influence on the earth's heat budget, snow and ice are prime movers because of their very high albedo. In both of these substances very large space scale variations can occur at very small time scales--for example, almost the entire midwest of the United States can make the transition from being snow-free, with an albedo of 0.3 - 0.4, to being covered with a light layer of snow, with an albedo of 0.8 - 0.9, in just a few days.

Perhaps in the whole field of geophysical investigations the most difficult area in which science is attempting to determine the cause and effect of nature is in the Arctic. Both polar areas are very difficult to study because of the great logistical problems, but I think it is fair to say that Antarctic work has proceeded very well, partly because the continent of Antarctica is a fairly stable platform. It is a high ice cap with ice 2-3000 meters thick which flows with typical slow glacier speeds (a piece of ice generated at the south pole takes tens of thousands of years to flow off the polar plateau and calve into the Antarctic Ocean). Also, in terms of understanding its energy balance, it is less complex than the Arctic because essentially no melting of the surface snow occurs over the plateau, therefore there are no great albedo changes, and no fractures exposing liquid water occur except in the sea ice surrounding the continent.

In comparison, the Arctic is extremely dynamic. The sea ice covering the Arctic Ocean is a mere veneer compared with the great Greenland and Antarctic ice caps. Its mean thickness is about 3 meters. Its motion is extremely rapid--individual ice floes within the multi-year ice canopy have been observed to move as fast as 50 km/day. In Figure 1 is shown the drift track of ice island T-3

for the last 18 years, during which it moved tens of thousands of
kilometers. In the Arctic summer the entire surface of the ice
canopy melts and great albedo changes occur very quickly over vast
areas. Not only do great motion and albedo changes occur within
the ice canopy, but the boundaries undergo large fluctuations so
that annually the mean areal extent of the Arctic sea ice fluctuates
about 10%. All in all, the sea ice cover is one of the most varia-
ble physical features of the earth's surface.

A key problem in Arctic research is to understand its heat and wat-
er budget at meso- and macro-scales in space and time. The sea ice
has a profound influence on the heat exchange within the Arctic
Ocean and between the ocean and the atmosphere. Knowledge of the
fluctuations of the snow and sea ice media and of their influence
on the earth-atmosphere interface is important in studies of
atmospheric circulation and the world water balance. Much of the
needed data, in the form of macro-scale synoptic images at short
time intervals, can potentially be achieved with the use of remote
sensing satellites.

Permafrost, Snowpacks, Glaciers, and Ice Caps

Essentially nothing is known of the temporal and spatial variations
of snow cover north of the Arctic Circle. Snow depths are measured
at a few points in that vast area, but these data are entirely
insufficient to meet present research needs, let alone help in
the future development of predictive computer models for the region.

On the land masses in Arctic regions the snow cover is a very
irregular and variable feature. A varying layer of snow lies on
the permafrost, glaciers, and icecaps most of each year. An under-
standing of the mass and energy balance of any of these ice features
is dependent upon the understanding of the energy balance of the
snow cover. It would be most useful to know the dates of the on-
set of snow melting and disappearance. Recent work by Meier and
Edgerton (1971) indicates that snow can be distinguished from many
other land surface materials using passive microwave radiometers,
and that microwave brightness temperatures vary with snow wetness,
snow density, ice layers, snow temperature, and base material.
Although the exact quantitative relationships between the micro-
wave brightness temperatures and each of these parameters is not
presently known, it is clear that an understanding of the physics
of microwave emissions by snowpacks is emerging and that an all-
season, all-weather means of monitoring snow packs is a real
possibility.

Over 25% of the Earth's surface is covered by permafrost (pereni-
ally frozen ground), and much more is subject to seasonal freezing
and thawing, yet it can safely be said that even less is known a
about its temporal and spatial variations than about snow cover.
Although study of permafrost by remote sensing promises to be more
difficult than in the case of snow and ice, it appears that both
active and passive microwave sensing may prove useful.

Considerable remote sensing work has been done on South Cascade
Glacier (in Washington state) by National Aeronautics and Space
Administration aircraft. Meier, Alexander, and Campbell (1966)
have shown that a variety of important snow and ice parameters
related to the glacier's mass balance can be studied by available
remote sensing techniques. Little work of this kind has been done
on Arctic glaciers. The current behavior of Arctic glaciers may
hold important clues to an understanding of worldwide climate
variations and trends. Perhaps the greatest problem remaining to
be solved in the field of glacier dynamics is the mechanism
controlling the glacier-bed rock friction. Of specific present
interest is the phenomenon of glacier surges, or sudden very rapid
movements of glaciers in which jumps in velocity of more than an
order of magnitude occur. The greatest known surge occurred on
Nordaustlanded (North East Land), Svalbard (Glen, 1941) and was
remotely sensed by photography by a Norwegian pilot. A few glaciers
in the act of surging and numerous ones that have surged have been
photographed by Austin Post of the U.S. Geological Survey, and his
work (Meier and Post, 1968) has shown that remote sensing is per-
haps the prime tool in studying the numerous glaciers of the
Arctic.

The Greenland ice cap is second in size only to the Antarctic ice
cap. It is comparable to the Antarctic, and Benson (1967) after
making many comparisons, both general and specific, feels that
the potential of using Greenland as a laboratory for polar ice
sheet research is good. The interaction of the ice sheet with
the surrounding ocean is an important area of research, especially
as it bears on determining the mass balance. Certain aspects of
the Greenland ice cap mass balance, such as snow cover, which is
more spatially homogeneous than elsewhere in the Arctic, might
be amenable to study using satellite imagery with its relative
poor resolution, but synoptic view.

The Arctic Ocean

The circulation of sea ice in the Arctic basin is an exceedingly
complex phenomenon. The seemingly chaotic drift trajectories
(Figure 1), which at present are understood theoretically for only
large period average drifts, are the result of an interplay between
forces whose exact physical basis is poorly understood. The long-
period circulation of sea ice in the Arctic Ocean can be said to
have two main features--the trans-polar drift stream and the Beau-
fort gyral. During the last 80 years the drift tracks of ships
embedded in the ice, ice islands of glacial origin embedded in the
ice, and select pieces of manned ice floes have given sufficient
data to delineate the trans-polar drift stream, which runs from
the Siberian coast, over the north pole, and out the Greenland-
Iceland trench, and the Pacific or Beaufort gyral, an anti-cyclone
which is centered in the Beaufort Sea and around which ice island
T-3 has been rotating for some time (Figure 1). The heterogeneous
character of the ice flow within the icepack results in strong
compressive shearing and tensile forces so that the icepack is
composed of ice floes ranging in size from pieces with an area as
large as tens of square km to pieces the size of ice cubes. Small
cracks between individual ice floes are called leads (Figure 2),
and the large cracks are called polynyas, the Russian word for pond
(Figure 3). When these openings close, usually a ridge is formed
(Figure 4). When thin ice forms in polynyas and is rafted over
itself in successive bands, finger ice forms (Figure 5). Until
very recently it was believed that the total area of the Arctic
Ocean which was open at any given time was very small--less than
1%. However, recent data (Wittmann and Schule, 1966) show that
throughout the year roughly 10% of the ice cover may be open water.
This figure is in keeping with the relatively large quantity of
young ice which has been observed, but contradicts much of the
supposedly well-established knowledge of the heat budget. Experi-
ments by Badgley (1966) indicate that the heat flow per unit area
through a lead or polynya from the ocean to the atmosphere is at
least two orders of magnitude greater than through the old sea ice.
These studies suggest that the heat budget of the entire ocean and
the flux of water from the ocean into the atmosphere are essentially
determined not by the ice but by the fractures in the ice.

Essentially nothing is known about the creation, movement, and
closing of polynyas. We have observed families of polynyas in
certain parts of the Arctic Ocean that had individual polynyas
with dimensions as large as 10 x 70 km. Families of polynyas of

this size have been observed in the center of the Beaufort Sea and north of Greenland, and in both cases overflights two days later revealed that the polynyas were gone. Most observers who have lived on the sea ice for any period of time have on occasion observed great shearing motions in their immediate area. The fragmentary and piecemeal evidence we have on polynyas indicates that they move with great speed and can occur in all parts of the Arctic Ocean. Present scanty data indicate that the formation of the polynyas is associated with cyclone passage.

The great part of the surface research in the Arctic Ocean has been carried out by a series of Russian and American ice floe stations. This kind of activity of single stations drifting at separate times at great distances apart in the ocean has failed to give any idea of the cause and effect of the polynya movement in relation to atmospheric, oceanic, and internal ice forces. Before any real understanding of the basic physics of the polynyas and the ice dynamics which produce them can occur, two things are necessary. 1) A means must be developed to acquire sequential, synoptic imagery of the Arctic Ocean during all weather and seasons. 2) Direct measurements of the strains in the sea ice canopy and the heterogeneous character of the air and water stresses acting on that canopy should be made for a group of drifting stations.

Satellite imagery has been shown to be useful in delineating large polynyas in sea ice. Nelson et. al. (1970) have demonstrated this using visible-spectrum images, and Barnes et. al. (1970) have done so using infrared images. A comprehensive study of airborne camera, infrared, and side-looking radar images and laser profile records of Arctic sea ice (Raytheon, 1970) shows that a great variety of extremely detailed information on sea ice morphology can be obtained from aircraft. In 1970 the National Aeronautics and Space Administration flew its two chief remote sensing aircraft, the NP-3 from NASA Houston and the Convair 990 from NASA-Ames Research Center, over the Beaufort Sea, and sensed the Arctic surface with a variety of instruments. Figure 6 shows a side-looking radar image of sea ice approximately 320 km north of Point Barrow, Alaska, obtained in the spring of 1970. Five fairly large polynyas having a preferred orientation can be distinctly seen. This image was obtained through a cloud cover several thousand feet thick.

Some of the most exciting sea ice data obtained recently are the passive microwave images of sea ice from the June 1970 Convair 990

flight (Nordberg, et.al., 1971). One very interesting aspect of
microwave sensing of sea ice is that at frequencies in the order of
30 gigahertz the apparent brightness temperature difference between
sea ice and open water is as much as 150°K, thus we have a tool
which will discern polynyas from floe ice or very thin finger ice
through a cloud cover. Figure 7 shows a passive microwave image of
multi-year sea ice with two large polynyas. The images also show
that large-scale variations in the ice surface texture are detectable
as contrasts in microwave emissivities. Brightness temperatures over
ice covered with dry snow are 5% lower (radiometrically cooler) than
over melted and recrystallized snow or bare ice surfaces.

Not only is the Arctic dark for half of the year, but most of the
important changes on both the sea ice and land areas occur when they
are covered by clouds. Therefore, the remote sensing tools of side-
looking radar (SLAR) and passive microwave appear to be the ones
that will prove to be most useful in Arctic geophysics.

A project to measure ice strains and air and water stresses on the
ice already exists. The Arctic Ice Dynamics Joint Experiment (AIDJEX)
was formed in 1970 by a group of interested American and Canadian
scientists as an interdisciplinary investigation designed to obtain
data about the ice canopy which will hopefully enable the creation
of predictive computer models for its dynamics and heat budget.
Investigators from Russia, Norway, and Japan have expressed a will-
ingness to join in this international study. AIDJEX will mount a
series of simultaneous manned drifting stations in the Beaufort Sea
region starting in 1973. Before these field experiments occur, a
series of pilot experiments will have been performed. The first
AIDJEX pilot experiment took place approximately 320 km north of
the MacKenzie Delta in March 1970. A similar small-scale experiment
took place in the same area in March 1971. Both of these pilot
expeditions experimented with means to measure ice strains, the
water and air stresses on the ice, and the structure of the ocean
currents. In March 1971 the NASA Convair 990 flew a series of five
missions over the AIDJEX expedition. Both low-level and high-level
data were collected with emphasis on SLAR and microwave sensors.
The U.S. Navy and Coast Guard also flew a series of missions over
the AIDJEX site. The comprehensive and detailed remote sensing and
ground truth experiment resulted in the best data of its kind ever
collected. These data will be invaluable in establishing design
criteria for the full-scale 1973 AIDJEX experiment.

Conclusions

The Arctic is an area in which nature's cause and effect can be
understood only with the help of the sequential, synoptic imagery
obtainable with remote sensing tools. A real need exists for
detailed data obtainable from aircraft and large-scale data
obtainable from satellites. Of apparent greatest potential are
images, both passive and active, in the microwave region.

A detailed, long-term, international experiment called AIDJEX is
already underway, but its great efforts can only be brought to
fruition with the aid of remote sensing data.

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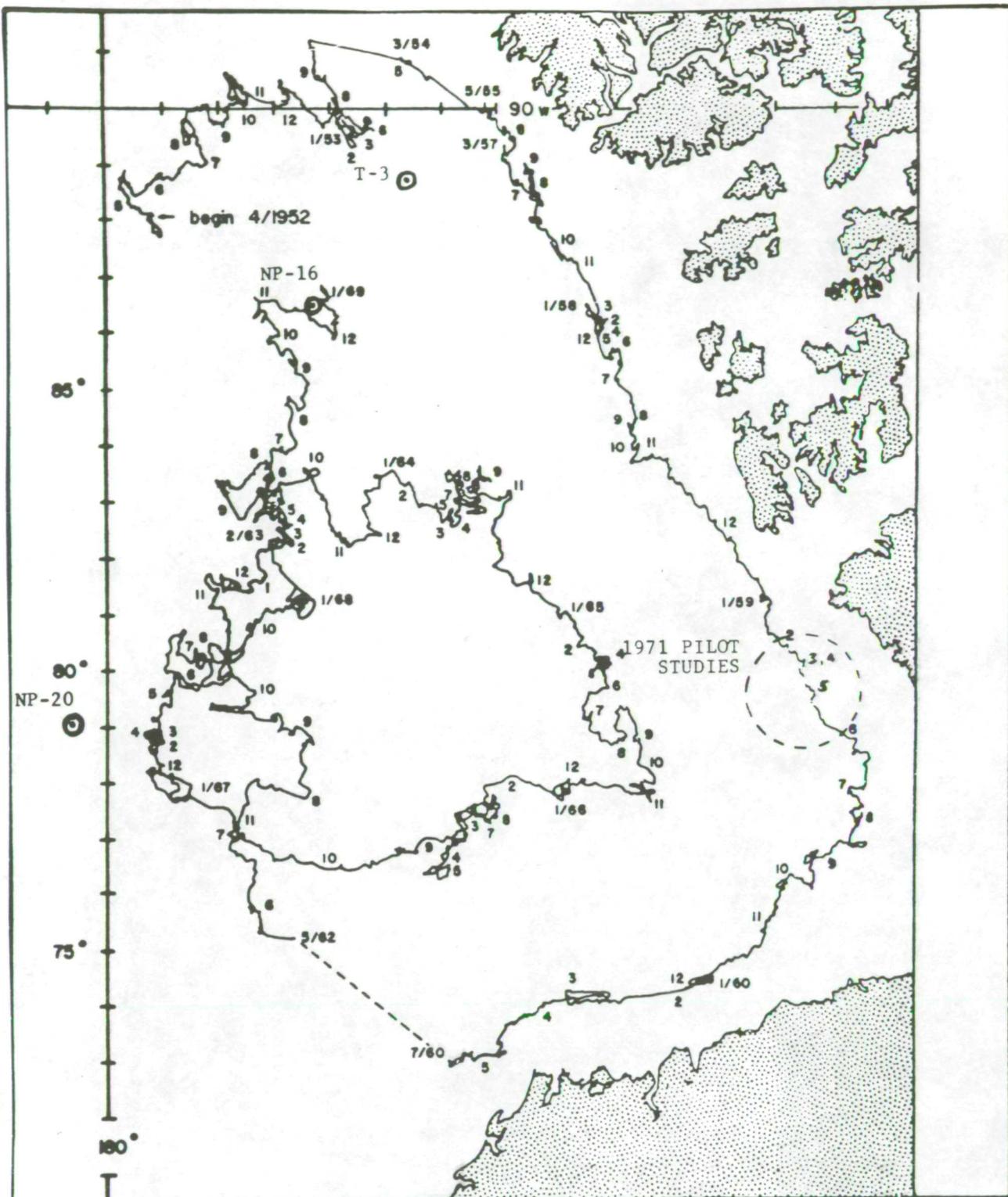
POSITIONS OF DRIFTING STATIONS ON SEPT. 9, 1970
AND T-3 DRIFT TRACK. WHERE WILL THEY BE
IN MARCH 1972 and MARCH 1973?

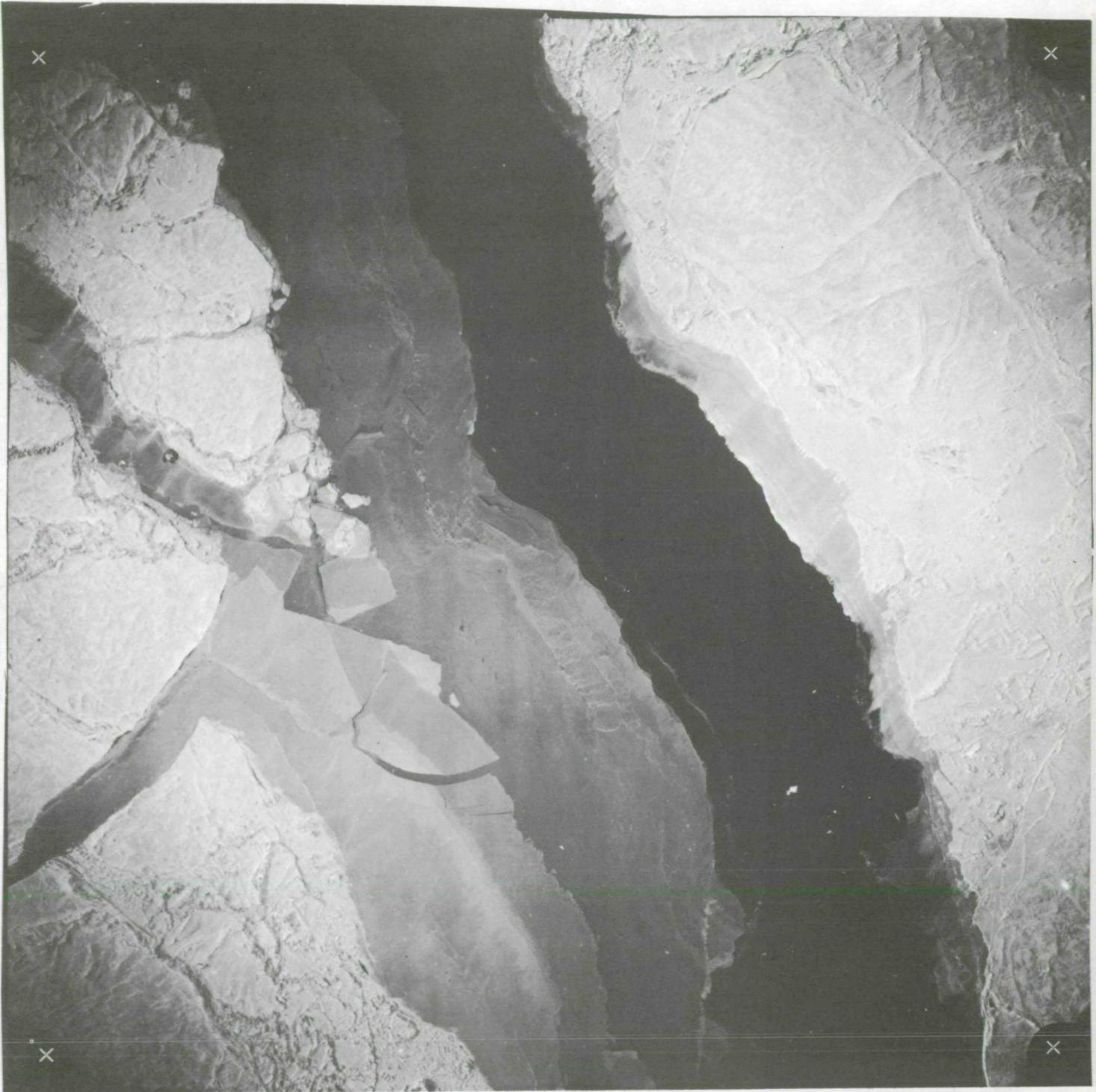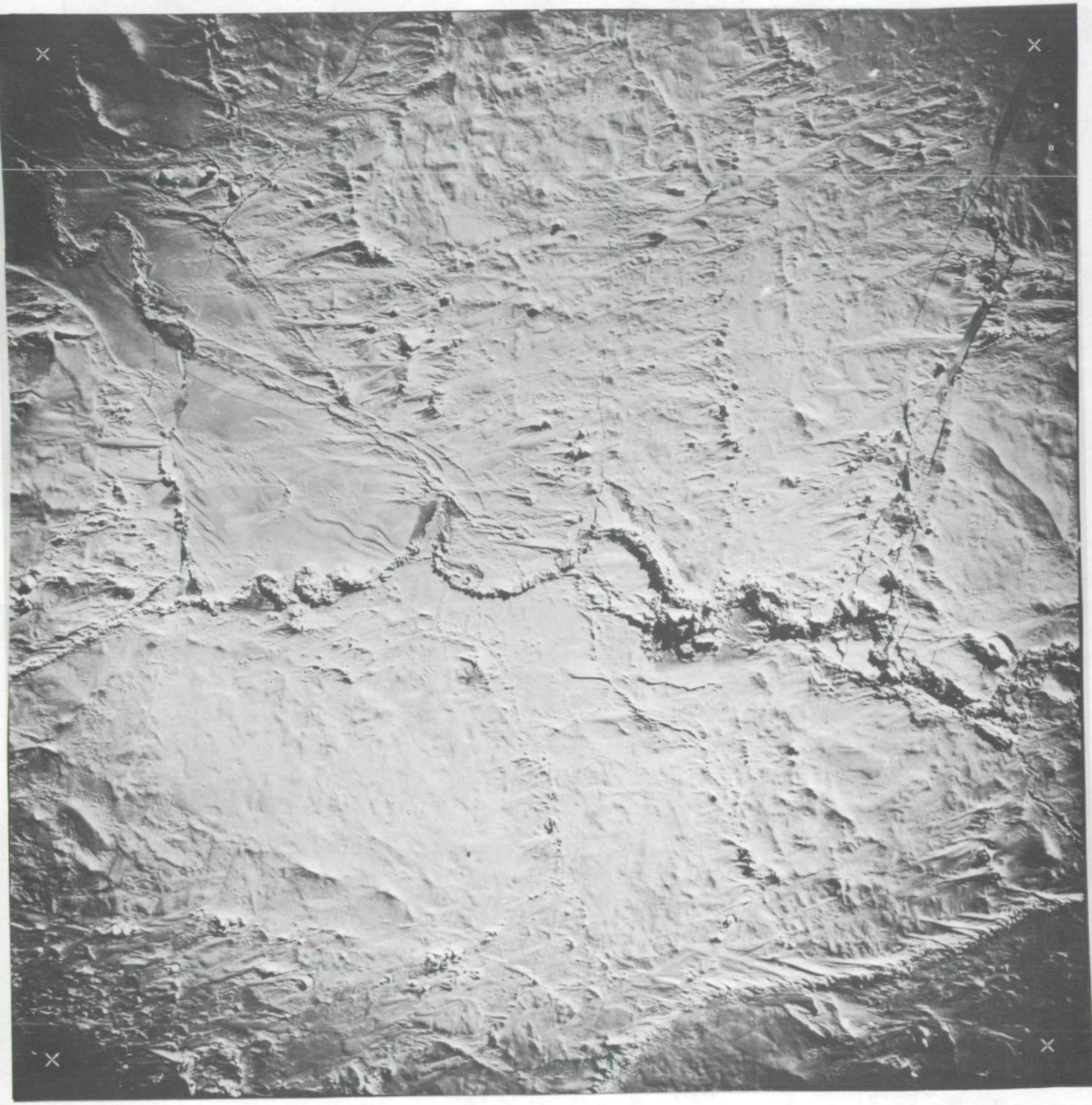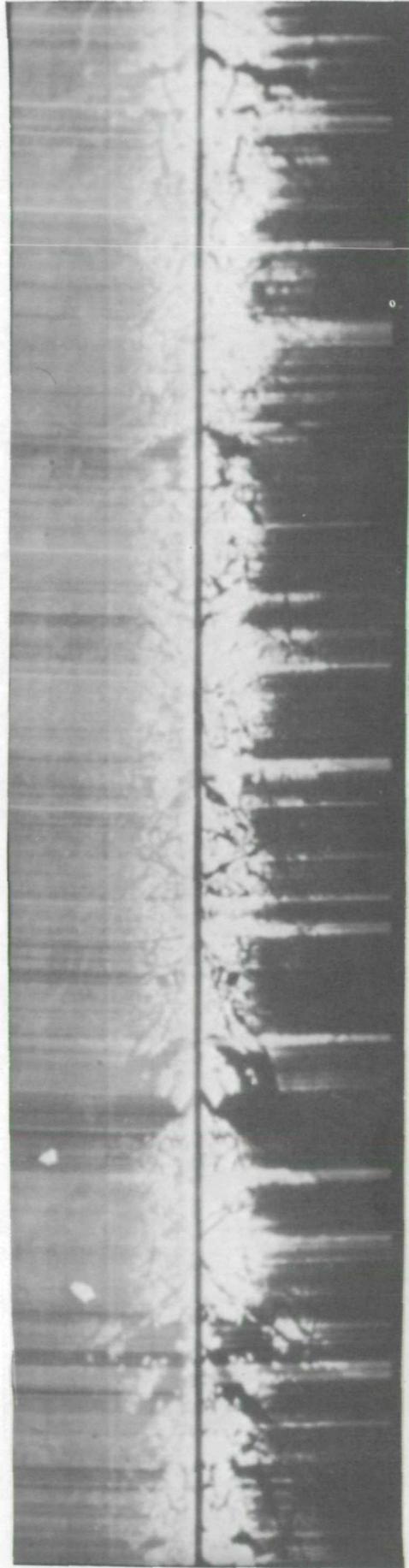|		
T-3	84.5N	103.1W
NP-16	85.1N	135.8W
NP-18	80.7N	144.9E
NP-19	78.3N	147.6E
NP-20	78.9N	177.3E

FIGURE 1

FIGURE 2

FIGURE 3

FIGURE 4
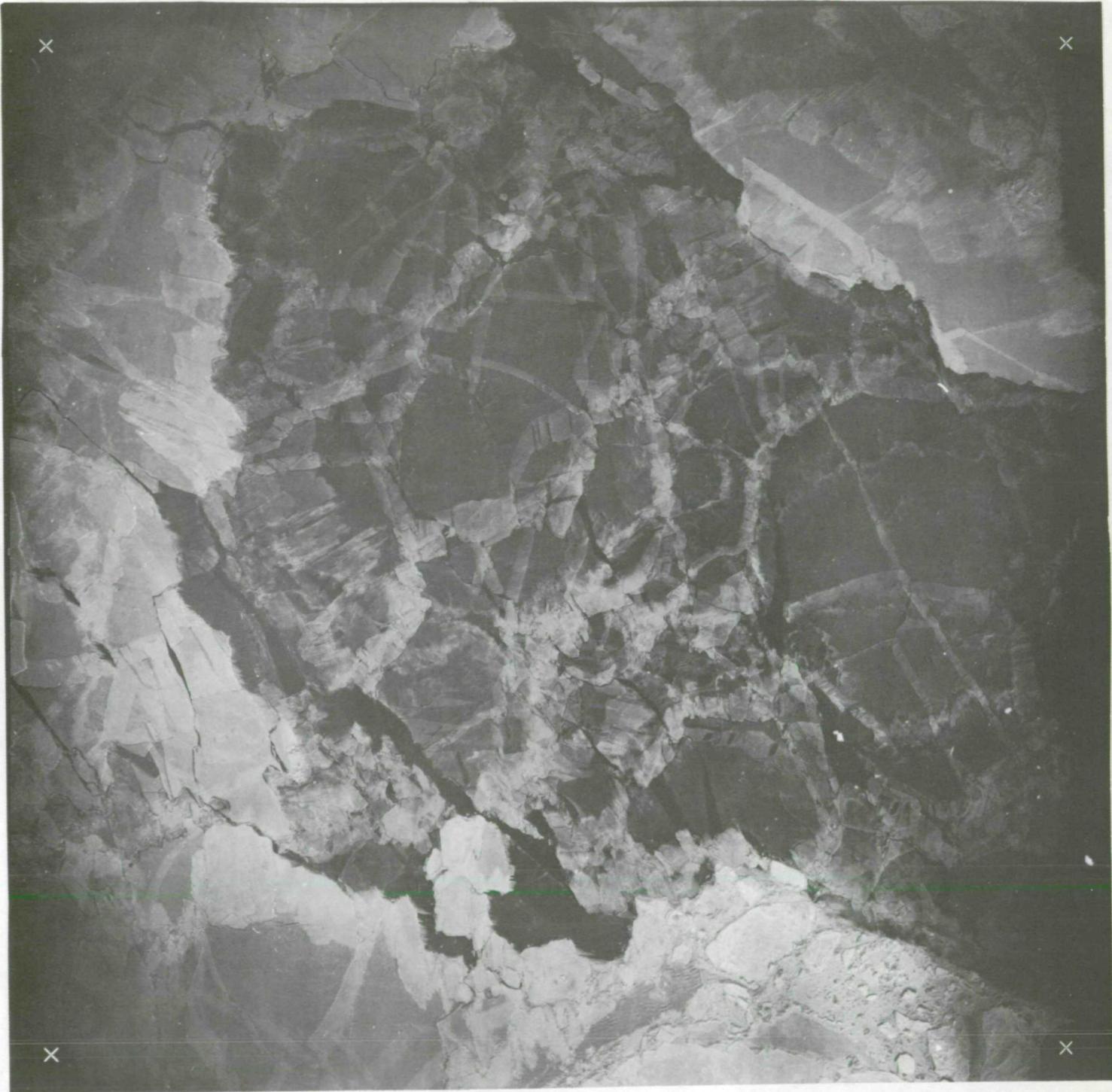
FIGURE 5

FIGURE 6

PASSIVE MICROWAVE IMAGE OF MULTI-YEAR SEA ICE WITH POLYNYAS (LARGE LEADS)
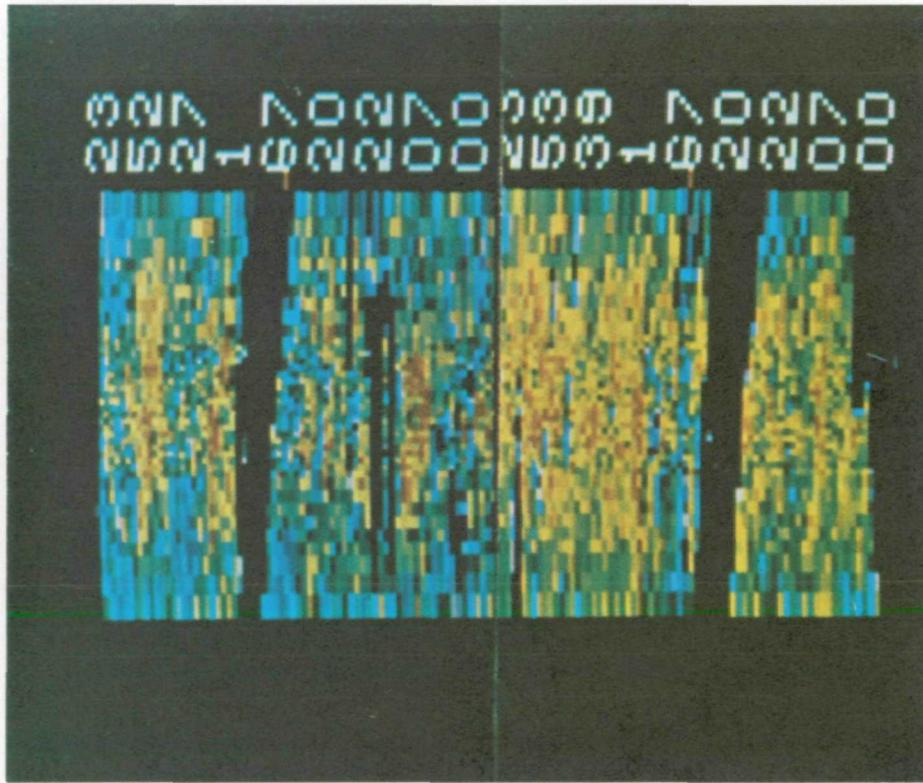
60-15

AIRCRAFT ALTITUDE	150 M	SENSOR WAVELENGTH	1.55 CM
AIRCRAFT SPEED	450 KM/HR	ANTENNA BEAMWIDTH	2.80
APPROX. DIMENSIONS	0.3KM x 30 KM	SCAN WIDTH	+500

FIGURE 7